for can be recognized in the memory image; that one is then the first. The second stimulus is wanting in this memory image in so far as the image results from an exact adjustment. The limit of the discriminable is reached, when it is no longer possible to fixate the first stimulus alone." This method was noticed by Exner only in the case of the separate stimuli to the two ears, and, while he thinks it may possibly have occurred in the other cases also, he is inclined to believe that the close resemblance of the two stimuli is an essential condition of its development. This restriction seems doubtful; at least, in the experiments of this study, no difference in type was noticed in the different combinations of stimuli. It is much more probable that this type is characteristic of experiments in which a single pair of stimuli are judged, and that the type which Exner found for stimuli to disparate senses belongs to the rhythmically recurring pairs of stimuli. As already explained, the two click experiments of Exner were the only ones where his apparatus seems to have allowed the production of a single pair.

The results of this study may be summarized briefly as follows:

1. The interval that must separate instantaneous stimuli addressed to disparate senses, or to different organs of the same sense in order that their order may be recognized, has been measured for single pairs of stimuli, and by a method as nearly as possible the same in all cases. The results of this measurement, besides indicating some changes in the figures commonly given for these intervals, make the explanation of the constant errors, found with the click and flash, by optical inertia apparently unnecessary.

2. The effect of voluntary attention has been examined, and so far as the experiments go, has been shown not to cause the stimulus for which attention is set to seem to lead in time. Throughout the experiments, on the contrary, the importance of spontaneous attention, or at least the spontaneous reaction of the psychophysical mechanism has everywhere appeared.

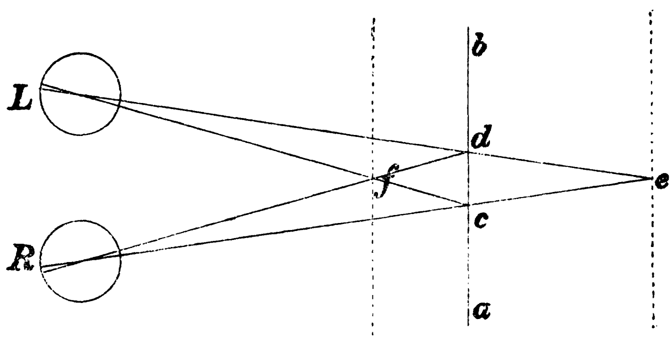
XI. Notes on New Apparatus.

By Edmund C. Sanford.

The Binocular Stroboscope. The purpose of this note is the double one of calling attention to a little known phenomenon of binocular vision and describing an instrument by which it

may be demonstrated. The phenomenon was long ago studied by Dvorák, but his paper is hidden away in the Proceedings of the Bohemian Royal Society of Sciences,[1] and has received little notice. The only contribution of the present writer is such a simplification of the instrument as makes the phenomenon demonstrable in any laboratory that has a vertical color-wheel and a mirror. The phenomenon in queston is, as the title of Dvorák's paper indicates, a sort of "personal equation" between the two eyes. If the right eye receives a stimulus and a little later the left eye receives another, the two stimuli, if close together, may seem simultaneous and be credited to a single cause, or, if further apart, may be recognized as separate and credited to separate causes. Quantitative measurements of the time that must separate two such stimuli were made by Dvorák and some preliminary work in the same line has been done in this laboratory.

The point of present interest is, however, not this general case, but the particular one in which the stimuli are separate glimpses of a moving object. When proper conditions are observed such successive glimpses are united into an illusory perception of distance. The nature of this illusion will be made clear by the following diagram:

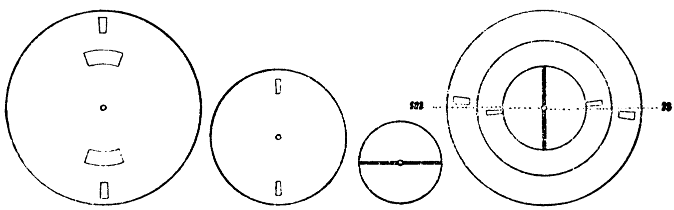


R and *L* represent the right and left eyes; the object moves in the line *a b*. Suppose in the first place that the object starts from *a* and moves upward, and that when it reaches *c* it is seen for an instant by the right eye and when it reaches *d*, for an instant by the left. The united perception will then be located at the intersection of the lines of sight, that is at *e*. If the order in which it is seen by the eyes is reversed (the

[1]Ueber Analoga der persönlichen Differenz zwischen beiden Augen und den Netzhautstellen desselben Auges. Sitz.-ber. d. k. böhm. Gesells. d. Wis. in Prag; Jahrgang, 1872. Jan-Juni, pp. 65-74.

direction of motion remaining the same), the left eye will see it at *c* and the right eye at *d*. In this case as before it will seem to be at the intersection of the lines of sight—this time at *f*. This is true for both direct and indirect vision, and gives a certain support — probably more apparent than real—to the old projection theory of visual localization.

The simplest means of getting such instantaneous glimpses of a moving object is to use a disk with radial slits as in the ordinary stroboscope. The instrument is easily made binocular by cutting separate slits for the two eyes, and both binocular and adjustable as to the order in which the eyes are used, by applying a smaller disk concentrically over the first. *A* and *B* in the diagram below are a pair of such disks.



A *B* *C* *D*

The moving object in Dvorák's apparatus was a broad band of paper with vertical stripes, placed a little distance behind the disks and driven by the same means as they. In the simplified instrument the moving object is a figure of some kind painted either directly on the smaller disk or on a third still smaller disk placed upon the same spindle as the other two. Such a figured disk is represented by *C*, and the moving object is the black bar which it carries. In *D* the disks are shown combined for use.

In using the instrument the combined disks are placed on the color-wheel, and at a convenient distance before them a mirror so set that the observer, looking through the slits from behind into the mirror sees the reflection of the face of the disks. The bar of the smallest disk should be vertical when the diameter that halves the angle between the slots, *mn* in *D*, is horizontal. The instrument may be used without further addition, the eyes being brought close to the slits at about the height of the spindle. It is better, however, to place between the eyes of the observer and the slits a screen of black cardboard with a narrow horizontal slit (placed radially with reference to the disk) so as to prevent the observer from seeing through the slits except when they are immediately before his eyes. When the instrument is thus set up, and the disks are so

adjusted that the right eye sees first, and the direction of rotation as seen in the mirror is like that of the hands of a watch, the observer sees the image of the bar inclined toward him at the upper end and away from him at the bottom. When the left eye leads the inclination is reversed. The effect is most striking when the lead of one eye over the other is rather small, for otherwise the positions of the bar are too discordant for easy spatial interpretation; a lead of five or six degrees is sufficient.[1]

The size of the disks must of course be varied to suit the machine upon which they are to be used. The following dimensions will probably be found convenient on most color-wheels: Radius of large disk, 15 cm.; of small disk, 10.5 cm.; of figured disk, 6.5 cm. Distance of outer edge of narrow slits in large disk from centre of disk, 14 cm.; of inner edge, 11.5 cm. Distance of outer edge of broad openings from centre of disk, 9 cm.; of inner edge, 6.5 cm. Distance of outer edge of slits in smaller disk from centre of disk, 9 cm.; of inner edge, 6.5 cm. Extent of broad openings in large disk, 40°; of narrow slits in both disks, 5°. If the slits are made too narrow the image of the bar is clear cut, but weak in illumination; if too broad the image is stronger but blurred. In other forms of the instrument it is often convenient to use more than two slits in each disk, but in this it is a disadvantage, for with more slits the bar is seen more frequently and in positions where the separate glimpses are not capable of a spatial interpretation. The result is a case of irreducible double images, as may be seen by using the disks when the bar of the figured disk is brought into the diameter that halves the angle between the slits.

Other distortions of the image of the disks in the mirror can sometimes be observed, but they can for the most part be easily explained on the principles already set forth.

A Model of the Field of Regard. The movements of the eyes and their effect on visual localization are an interesting, but somewhat difficult topic in the psychology of vision. One

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[1]Another satisfactory figure is one which consists of a couple of heavy black rings placed near where the ends of the bar now lie in *C*. When this figure is used and the right eye leads, the upper ring will look smaller and nearer, the lower one larger and further away. A still more interesting case, but one which requires an independent moving object, is that in which the object moves in a horizontal circle, a vertical wire, for example, moving upon a circle three or four inches in diameter. When seen through the disks its path seems to be elliptical, the apparent direction of the long axis of the ellipse and the direction of the motion depending, in part, at least, on the order in which the eyes are used.

difficulty is getting a notion of what the hemispherical field of regard looks like and what its relations are to the plane field on which experiments are generally made. To assist in removing such difficulties as these, the model about to be described was constructed. A stereoscopic picture of the part that represents the hemispherical field, and an ordinary diagram of the part that represents the corresponding plane field will be found in the appendix to the section of laboratory experiments on the Visual Perception of Space given below. A detailed account of what the model presents is given at the same place and may be omitted here.

The general plan of the model will easily be understood by reference to the stereoscopic figure. The framework is of wood, its most important portion being the face board — that carrying the letters—which is twenty-eight inches square—seven eighths of an inch thick, and has a twenty-four inch circle cut from its centre. To this are fastened at *A*, *B*, *C* and *D* semi-circles of brass of two-inch radius and three sixty-fourths of an inch thick. To these were first soldered the prime meridian *A B* and the equator *C D*. The wires used were of iron and about three thirty-seconds of an inch in diameter. The wire when bought was coiled with a radius nearly equal to that of the hemisphere to be constructed so that little bending was necessary. The remaining meridians were next soldered in their places upon *C D* and on the brass plates at *A* and *B*, and after them the parallels and the oblique circles *E F* and *G H*. The crosses, cut from tin, were then put in place and finally the small circles *I J*, *K L*, *M N* and *O P* — Helmholtz's Circles of Direction — and the whole completed by painting the face board and wires a dull black.[1]

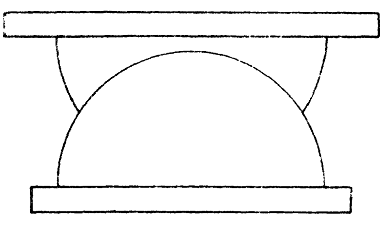
It was not at first intended to have the model show the relations between the hemispherical and plane fields of regard. In the present form of the instrument this has given place to a wide and thin board which slips into place behind the wire hemisphere and stands for a plane tangent to the latter at the middle point of the central cross. On this has been drawn a gnomonic projection of the wires and crosses of the hemispherical field, in other words, the figures that would be made by the shadows of these parts cast by a point of light in the centre of the lettered circle. These projections may be gotten mathematically by calculation or empirically by actually casting the shadows and tracing them. The diagram in the appendix was drawn by calculation, but

[1]The white letters were made by tracing from a stencil on bits of cardboard and then painting over all other parts with black.

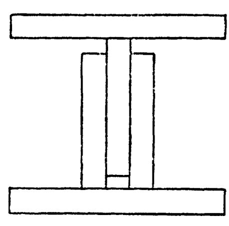
with the actual model the shadow plan was chiefly used as promising to accommodate itself more easily to small accidental irregularities in construction. By this combination of the plane and hemispherical fields the student can instantly satisfy himself that what he sees in one field is in reality an exact representation of what he sees in the other by bringing his eye to the centre of the hemisphere and seeing that the lines coincide.

The instrument as described is large and suitable for class demonstration. An instrument one quarter the size would answer equally well for individual inspection and would be much less cumbersome ; indeed, the stereoscopic diagram, in connection with the corresponding diagram of the plane field, serves almost every purpose. The writer has had a few extra copies of both struck off, and will be glad to furnish them, as long as they hold out, to any one interested in them.

A Simple Adjustable Stand. This piece of apparatus is easily within the skill of any one that handles ordinary tools. Its plan will be clear from the diagram below. It consists of a base board twelve inches long, eight wide and seven-eighths of an inch thick. Lengthwise of this and seven-sixteenths of an inch on either side of its middle line, are placed two vertical semicircles of wood, of five-inch radius and seven-eighths of an inch thickness.



SIDE PLAN.



END PLAN.

The upper part of the instrument is like the base board, except that it has a single semi-circle of wood along its middle line, and that it is a little larger — fourteen by ten inches.

When the instrument is put together, the semicircle of the upper part slips in snugly between the semicircles of the lower part, and the whole is fastened in any required position by means of an ordinary iron clamp, which squeezes the lower semicircles against the upper. The instrument made

in this way allows an angular adjustment of 90° in either direction from its middle position, and a vertical adjustment of three inches or more. When the clamp has just brought the sides together, the parts slide upon one another, and will retain any position given them, but when the clamp is screwed solid, the whole is as rigid as if made of a single piece. It is, of course, not necessary to use semicircular boards for connecting the base board and the top; almost any shape will serve, and some other shapes give even a greater range of adjustment.

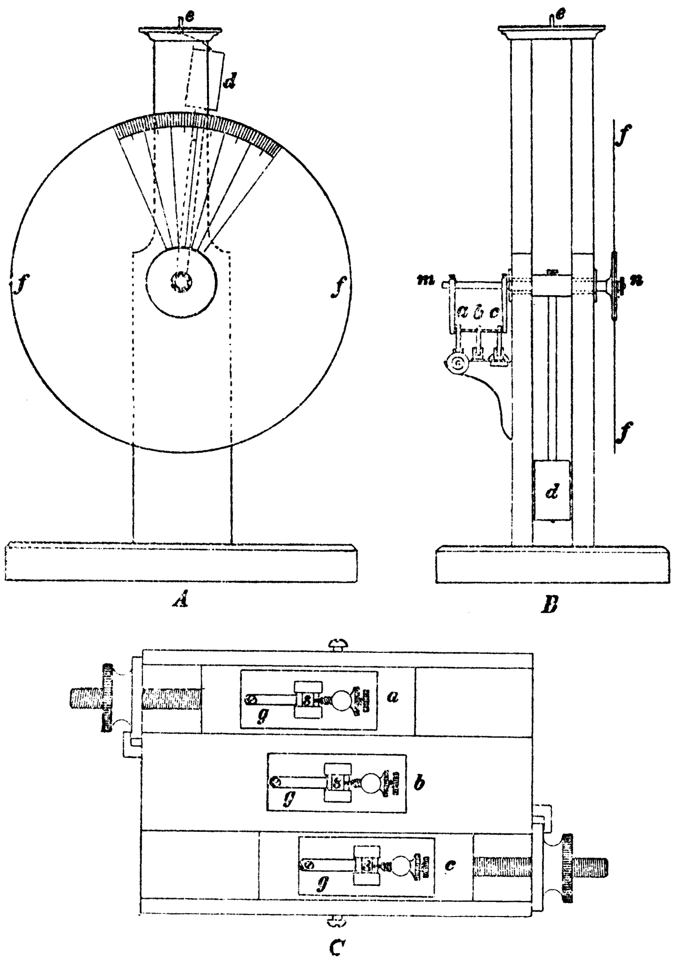
The stand was first designed to serve as an arm rest when it is desired to support the arm without keeping it absolutely motionless. For this purpose, a square bottomed, opened-ended trough of wood is used on top of the stand. This trough is twelve inches long, six wide and four deep, with a slack piece of cloth tacked across the top. The usefulness of a stand with such a range of adjustment, however, is obviously not limited to furnishing an arm rest.

The Pendulum Circuit Breaker. It was the purpose of this instrument to break three electrical circuits at known, and regulable intervals of time from one another. The familiar method of a swinging pendulum was used, but some adaptations have been made which have proved convenient in use and may justify a description. The instrument is that referred to in Minor Study, No. X, and is pictured in the cut on the following page:

The pendulum (*d* in Figs. *A* and *B*) is of brass and swings completely over on the axes *mn*, between the two upright posts of wood. The latter are of pine, one and one eighth of an inch thick, five inches broad at the bottom, and two and three quarters at the top, securely fastened into a base of the same material (eighteen inches long by twelve wide), and further braced together by a wooden cap at the top. The pendulum is a foot long and weighs, rod and bar together about three pounds. It is dropped from the nearly vertical position seen in Fig. *A*, by pulling back the release *e*. The keys are not struck by the pendulum itself as is common in such instruments, but by a striking bar or frame-work of brass, extending downward from the shaft *mn*, shown in contact with the keys *a*, *b* and *c* in Fig. *B*.

The other end of the shaft *mn* is finished like the spindle of a color-wheel for receiving a large disk *ff*. As used in Study No. X, this disk was of tin and about seventeen inches in diameter. Three functions may be performed by the disk: It furnishes a surface that can be smoked over and used for timing the pendulum chronographically; it furnishes a means,

when pierced with a radial slot and illuminated from behind, of producing a very brief flash of light; and, by the scale of degrees scratched on its edge, it furnishes a means of setting the keys without the use of their micrometer screws. In



Study No. X, it was used only for the first and last purposes, the flash being produced in another way.

Fig. *C* gives a plan of the keys as seen from above. Keys *a* and *c* were movable, key *b* was fixed in a central position,

so chosen that the striking bar was just in contact with it when the pendulum was at rest in its middle position. The shelf on which the keys stood was of iron, and each had to be insulated from it; they were, therefore, set on pieces of hard rubber, *g*, *g*, *g*. The upright arms of the keys are lettered *s*, *s*, *s*, and each was so shaped at the bottom that when it was erect, it was held in place by the spring (near the *g*'s in Fig. *C*), and when it was thrown down it was prevented by the same spring from rebounding. On either side of the shelf was a set screw for fastening the keys in place when once adjusted. The micrometer screws attached to *a* and *c* could have been used for setting them, but it seemed better in Study No. X, to use the screws for making small changes in the position of the keys, and to do the setting directly from the disk as already mentioned.

The setting was accomplished as follows: The disk *ff* being clamped tightly in place, a fixed point was fastened to the base of the instrument and brought close up to the lower edge. The keys *a*, *b* and *c* were connected with circuits in which were telephones or other apparatus for announcing the instant at which the respective keys were struck and their circuits broken. The pendulum was then lowered by hand and carried slowly by its middle position, and an exact reading obtained of the point on the degree scale at which the click announced that a key was struck. The whole degrees were shown by the scale, the tenths were estimated by eye. By chronographic measurement it had previously been determined that one degree corresponded to 1.6σ, and knowing this it was easy to set the keys to any required interval.

In using the instrument for the production of two nearly simultaneous stimuli in reversible order as required in Study No. X, the keys were so connected with the stimulation apparatus that the break at *b* gave one stimulus, *e. g.*, the flash of a Geissler tube, and that a break in either *a* or *c* (by parallel wiring) gave the other, *e. g.*, a click in a telephone. Whether the click should lead or follow the flash, was then controllable at will by a switch in the hands of the operator, all three keys being set up each time.

The value of such a piece of apparatus depends on its accuracy. The following records of chronographic tests with a Deprez signal and tuning-fork, giving approximately 149 vibrations per second, show a degree of accuracy very satisfactory for all purposes for which the instrument is likely to be used. The table gives the average number of vibrations of the fork for the 60° at the bottom of the pendulum's arc:

Table Showing Average Rate of the Pendulum.

Date.	Number of Trials.	Average. No. of vib.	Mean Variation.	Maximum.	Minimum.
J-7	22	14.13	0.06	14.25	14.00
J-22	34	14.15	0.07	14.30	13.95
A-3	14	14.13	0.09	14.30	14.00
A-3	12	14.08	0.05	14.20	14.00

Whether the keys were raised so that they were struck by the pendulum, or were turned down so that it swung free, made no appreciable difference in its rate. Of the two sets of tests on August 3, the first was taken after the instrument had been used for several days without re-oiling, the second immediatly after fresh oiling. The oiling appears to have reduced the time for 60° by about seven one hundredths of one tuning-fork vibration (roughly 0.5σ), or about one part in two hundred.

The advantages of this instrument are the swinging of the pendulum completely over and the attachment of the disk for chronographic control of its rate and accuracy. The pendulum rises well up at the end of its swing, and is easily caught by hand and carried on till it rests again at *e* ready for another fall. The complete swing makes the apparatus compact by bringing the catch from which the pendulum falls above the axis instead of at one side, and also avoids the backward swing which is often a considerable inconvenience in the common form of the pendulum chronograph. The advantage of the disk over a plate fastened to the pendulum itself, is the greater ease of adjusting writing points to a surface with which they are constantly in contact.

A pendulum of this kind with the attached disk is probably the simplest and cheapest time apparatus at present attainable for reaction-times or any other brief time intervals. With a disk permanently scratched with lines corresponding to hundredths of a second (following an idea suggested by Bowditch for a similar purpose) or even thousandths, determinations could be made both rapidly and accurately, especially if one of the keys *a*, *b* or *c*, were used for giving the stimulus so that the time to be measured should always begin at the same place in the swing.